

IN THE SPECIFICATION

Please amend the specification as set forth below.²

[0003] The present invention relates to a method for ~~predicting~~ assessing life-affecting damage on a rotary member that is subjected to repeated loading during operation. The method includes measuring a number of operating parameters and calculating a temperature increase during each loading from the operating parameters. A total temperature in a part of the rotary member is calculated for each loading by summation of a basic temperature of the rotary member before the loading concerned, and the temperature increase, and the values for the total temperature are used as a measure of the damage.

[0006] However, it has become apparent that it would be desirable to have a method for ~~predicting~~ assessing consumed life, which provides a more accurate result compared with the system according to U.S. Pat. No. 5,723,779.

[0008] One object of the invention is to provide a method that yields an accurate ~~prediction~~ assessment of damage caused in a rotary member that is loaded in operation in an effective manner in terms of computer capacity.

² There are discrepancies between the paragraph numbers in the specification as filed and as published since two of the subsection headings in the beginning portion of the application were incorrectly given paragraph numbers in the published specification and certain formulae in the specification were given paragraph numbers in the application as filed but not as published. The paragraph numbers used herein are the paragraph numbers used in the specification as filed, not as published. Additionally, certain amended paragraphs presented in the May 24, 2007 Amendment have been objected to for various informalities. Where those paragraphs are being re-amended and/or further amended, the amendments herein will begin with the paragraphs as so previously amended, not as originally presented.

[0016] According to another preferred embodiment of the invention, each of the graphs of the functions has such a shape that a logarithmic first expression for the temperature increase changes linearly as a function of a logarithmic second expression for the nature of the rotary member and the duration in time of the loading. More precisely, the second expression is calculated as a power function of the duration in time of the loading divided by a value for the nature of the rotary member. This calculation of the temperature increase affords opportunities for a very accurate value of damage caused/life consumed by each cycle of loading to be determined.

[0026] FIG. 1 diagrammatically shows in block format a system 1 for implementing a method for predicting assessing damage to, or consumed life of, a member 2 intended for rotation and having surfaces subjected to friction. In the description below, the rotary member 2 is exemplified by a brake disk for the purpose of facilitating understanding of the disclosure. It is assumed that the temperature changes in the brake disk during brake applications have decisive significance for the disk's life. By means of the method below, consumed life of the brake disk is therefore predicted on the basis of these temperature changes.

[0034] Calculation of Temperature Increase: According to the present invention, a value for what is known as a Fourier constant, F_o , is calculated first. This Fourier constant is dependent on the material thickness and other, heat-related attributes or characteristics of the brake disk, and also the time for which the brake disk is activated. More precisely, the Fourier constant, F_o , is calculated as follows:

[0035] $[F_o] \ F_o = 4 \cdot \alpha \cdot t / S^2$, where

[0042] According to a first embodiment of the invention, one of two different functions K, L (See Figure 2) is selected on the basis of the Fourier constant calculation. Each of the functions is described by a straight line in the diagram. The two linear functions have different slope coefficients and intersect one another. With the aid of the function selected, an expression for the temperature increase is obtained. More precisely, the diagram has the Fourier constant on the x-axis and the expression for the temperature increase on the y-axis. Both the x-axis and the y-axis have logarithmic scales. In the specific embodiment, the first function K is used when Fo is less than 0.5 and the second function L when Fo is greater than 0.5. Because the functions intersect, either function could be used with the same result in the event Fo is equal to 0.5, which is where the functions intersect.

[0053] From reference [2], an expression is derived for the surface temperature increase in the case of a rectangular thermal pulse. In an analogous manner to calculation (1) above, this can be converted to:

[0055] The functions (1) and (2) apply when Fo is greater than 0.5.

[0058] where $t/to = Fo$, with t being $[[=]]$ equal to the duration of the thermal pulse $[[.]]$ and to , which is equal to $S^2/(4*\alpha)$, $[[= S^2/(4*\alpha)]]$ being a constant characteristic of the disk.

[0061] The specific expression for the function for the fitted curve L can be produced with known curve-fitting methods. This expression is therefore used as a function for calculating the maximum temperature increase ΔT on the surface $[[for]]$ when Fo is greater than 0.5.

[0065] According to a second preferred embodiment of the invention, In the abovementioned total appraisal or curve fitting of the function, adjustment for triangular load ~~and the function or~~ for rectangular load ~~in order to arrive at a function (K and, respectively, L) in~~ determining the functions K and L is not carried out. [[Use]] According to a second preferred embodiment of the invention, in contrast, use is instead made of a first set M of two functions M1, M2 when Fo is below a specific limit value and a second set N of two functions N1, N2 when Fo is above this specific value (FIG. 3). The two functions in each of the sets M, N correspond to different loading types. More precisely, the functions M1 and N1 ~~describe~~ pertain to a rectangular load, and the functions M2 and N2 pertain to a triangular load.

[0062] The type of load shape being applied to the brake disk is determined on the basis of measured operating parameters. The first function M1 and, respectively, N1 are used if being applied to a rectangular load, and the second function M2 and, respectively, N2 are used if being applied to a triangular load. The limit value used for Fo is 0.5 in this case as well. Thus, for rectangular loading, the function M1 is used if Fo is less than 0.5, whereas the function N1 is use if Fo is greater than 0.5. Because the functions M1 and N1 intersect, either function could be used with the same result in the event Fo is equal to 0.5, which is where the functions intersect. Similarly, for triangular loading, the function M2 is used if Fo is less than 0.5, whereas the function N2 is use if Fo is greater than 0.5. Because the functions M2 and N2 intersect, either function could be used with the same result in the event Fo is equal to 0.5, which is where the functions intersect.

[0070] For what is known as a triangular load, $E = P_{\max} * t/2$, and for a rectangular load, $E = P_{\max} * t$, where P_{\max} is the maximum power and t is the braking time. $E/(P_{\max} * t)$ is therefore calculated, which provides a measure of the shape of the loading. The calculated value $E/(P_{\max} * t)$ is compared with a limit value; if the calculated value lies above the limit value, the load type is considered to be rectangular, and if the calculated value lies below the limit value, the load type is considered to be triangular. The limit value is selected in the time range 0.5-1.0, and suitably the value 0.8 is selected. The value 0.5 corresponds to a pure triangular pulse, and the value 1.0 corresponds to a pure rectangular pulse. Use is then made of the function that corresponds to the value worked out.

$$[0086] T^{m1} * N = C1; \text{ therefore, } N = C1/T^{m1} = C1 * T^{-m1} \text{ (applies for curve P)}$$

$$[0087] T^{m2} * N = C2; \text{ therefore, } N = C2/T^{m2} = C2 * T^{-m2} \text{ (applies for curve O)}$$

[0092] ~~With the aid of Under~~ a linear part damage theory (Palmgren-Miner), total accumulated damage D to any given point in time may be expressed as the sum, over all encountered loading ranges, of partial damage n/N accumulated within each loading range, i.e., $D = \sum n/N$. Therefore, substituting the expressions above for N into that expression, two accumulated damage values D1 and D2 can be expressed as ~~are evaluated from the measurements~~

$$[0093] D1 = \sum n_1 / (C1 * T^{-m1}) = \sum n_1 C1^{-1} * T^{m1} = C1^{-1} * \sum n_1 * T^{m1} S(T^{m1} * n1)$$

(applies for the curve P)

$$[0094] D2 = \sum n_2 / (C2 * T^{-m2}) = \sum n_2 C2^{-1} * T^{m2} = C2^{-1} * \sum n_2 * T^{m2} S(T^{m2} * n2)$$

(applies for the curve O)

[0097] D is damage value per unit of time or distance (damage per hour or damage per kilometer), and $[n_1]$ n_1 and n_2 are the number of braking cycles per temperature level and unit of time or distance.

[0108] For example, the prediction assessment of damage/consumed life described above can be carried out for crack formation in brake disks or linings. Cracked brake disks are a not unfamiliar phenomenon. There is a close connection between stresses/strains and temperature and gradients. As we are measuring temperature and number of braking cycles, we have a basis for predicting the time of initiation and growth of cracks in disks and plates. This presupposes, like the case for wear, that we have carried out rig tests that describe the relationship between temperature cycles and crack formation. This can also be described with power functions and thus be handled in an analogous manner to wear as above. An example of calculation of crack formation in brake disks or linings is described below.

$$[0110] \quad \sigma = \frac{dT \cdot \alpha \cdot E}{(1-\nu)} \quad \frac{dT \cdot \alpha \cdot E}{(1-\nu)}$$

[0113] ν = Poisson's constant

[0118] According to another example, the prediction assessment of damage/consumed life described above can be performed for a gearwheel in a gear train. A certain wear phenomenon on gears can be treated using the same model as was used above for brakes. Such wear occurs in connection with transmission of relatively great torques at high sliding speeds. The critical problem consists in carrying away sufficiently rapidly the heat generated in the engagement by the friction. The problem is therefore analogous to the problem we solved for brakes. The damage durability is obtained from rig tests. Time-integrated torque and speed provide a measure that is proportional to the energy developed in the contact surfaces. Periods with high torques/speeds can be regarded like the braking cycles as above. More precisely, the oil film between two contact surfaces can be broken down at high loads, which produces considerable tooth wear. The time between loadings is the time it takes for a gearwheel contact surface intended for engagement to move to the next engagement instance.